DETERMINING THE DRILLABILITY OF FERTILIZERS

By
CHARLES W. GANTT
WALTER C. HULBURT
HERBERT F. RAPP
JOHN O. HARDESTY

Production Research Report No. 17

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

CONTENTS

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of G. A. Cumings (deceased), formerly agricultural engineer, Agricultural Engineering Research Branch (now Division), ARS, who contributed valuable suggestions on designing the equipment used in the tests described in this publication; also, R. M. Magness, formerly chemical engineer, and J. B. Breen, formerly physical science aid, Soil and Water Conservation Research Branch (now Division), ARS, who assisted in the experimental work.

Washington, D. C. Issued July 1958

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.—Price 15 cents

DETERMINING THE DRILLABILITY OF FERTILIZERS

By Charles W. Gantt and Walter C. Hulburt, agricultural engineers, Agricultural Engineering Research Division, Agricultural Research Service; and Herbert F. Rapp, former chemist, and John O. Hardesty, chemist, Soil and Water Conservation Research Division, Agricultural Research Service.

SCOPE and PURPOSE

The use of large proportions of soluble hydroscopic salts in many present-day granulated mixed fertilizers has resulted in the need for an improved method of determining the effect of moisture absorption on the drilling properties of typical fertilizers now being manufactured or proposed for manufacture. Such a method for the examination of commercial and experimental products is described in this publication.

Formulation of high-analysis, mixed fertilizers often involves the use of large quantities of economical fertilizer nitrogen in the form of ammoniating solutions containing hygroscopic compounds, such as ammonium nitrate and urea. Many mixtures formulated with these materials are granulated, dried, coated, and packaged in high-grade, moisture-resistant bags to improve their storage and drilling properties by reducing segregation, caking, and moisture absorption during storage and transportation. A granular fertilizer that is dry, uniform, and lump-free upon removal from the bag can be expected to drill satisfactorily if used immediately.

However, a factor to consider in evaluating the ultimate drillability of a fertilizer is the effect of moisture absorption on its distribution during the drilling operation. When a hygroscopic fertilizer is exposed to high humidity during the drilling operation, the rate of application may change and the flow may become irregular.

455569°—58

DEFINITION and DETERMINATION of DRILLABILITY

Drillability of a fertilizer may be defined as a measure of the uniformity with which its plant nutrients can be applied to the field by a fertilizer drill. This implies that perfect drillability represents a uniformity of flow through the fertilizer drill that will result in an equivalent amount of nutrients being supplied to all crop plants in the fertilized area. Such uniform application is of utmost importance in securing maximum benefits from the fertilizer (*4*, *5*).[1] Drillability is influenced by such properties of the fertilizer as size and shape of the particle, segregation of particles, caking tendency, apparent specific gravity, and hydroscopicity (*3*, *6*, *7*).

Laboratory measurements of the angle of repose, apparent specific gravity, and average particle size of the fertilizer have been found to give values relating to its physical condition which could be used to calculate the coefficient of its rate of flow and hence its drillability (*2*, *4*). Ross and coworkers (*11*) studied the drillability of granular ammonium nitrate under partially controlled laboratory conditions. Their method consisted of collecting and weighing fertilizer delivered to separate containers mounted on a carriage moving at a constant rate beneath the drill. The equipment, although used indoors, was not housed in an air-conditioned room because of its length.

The equipment used in the tests discussed in this publication is a modification of that used in the previous work. These drillability tests were conducted under controlled atmospheric conditions in an air-conditioned room; this made it possible to evaluate the drillability of a hygroscopic product in terms of the length of time it will drill uniformly after the bag is opened and the material exposed to the atmosphere during the drilling operation. This modified method should enhance the value of tests conducted to predict the drillability of fertilizers under field conditions.

DRILLABILITY TESTS

Materials Used

Analyses of the 14 fertilizers used in these tests are given (table 1). Of the fertilizers listed, 5 were nitric phosphates, 1 was prilled ammonium nitrate, and 8 were mixed fertilizers; 5 were commercially manufactured, while 9 were experimental mixtures prepared by United States Government agencies.

---

[1] Italic figures in parentheses refer to Literature Cited, p.10.

TABLE 1.—*Analyses of fertilizers*

Sample number	Nominal grade	Chemical analysis: Total N	Chemical analysis: Total P_2O_5	Chemical analysis: Available P_2O_5	Chemical analysis: K_2O	Screen analysis: Amount passing U. S. screen No.— 4	6	8	12	16	20	40	50	100
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	5–20–20	5.2	22.3	22.0	17.2	100	96	73		12	1	0		
2	[1] 6–8–4	6.0	9.2	8.3	4.7	100	98		88		72	52	39	19
3	[1] 6–9–12	6.0	9.9	9.6	10.7	96	87		55		26	8	2	1
4	[2] 8–12–12	7.8	11.6	11.4	12.1		100		27		3	1	1	0
5	8–16–16	8.1	17.3	16.9	15.2	100	98	87		25	3	0		
6	8–24–0	8.2	25.0	24.7		100	97	75		14	2	0		
7	[3] 11–11–11	11.5	11.9	11.4	11.1				100		62	16	1	
8	[4] 11–22–11	11.4	23.6	23.1	11.8		100	88	60		9	0		
9	[5] 12–12–12	12.0	12.4	12.4	12.9		100	99		19	3	0		
10	12–12–12	11.9	13.2	12.9	11.8	100	97	83		38	9	1		
11	[3] 14–11–11	14.1	11.7	11.3	11.6				99		35	2	0	
12	15–10–10	15.0	11.0	10.8	9.9		97	83		30	8	2	0	
13	[3] 17–22–0	16.9	23.2	22.4					100		51	7	1	
14	[6] 33–0–0	33.5					100				7	2	1	0

[1] Commercial nongranular mixture.
[2] Commercial granular mixture.
[3] Experimental granular nitric phosphate prepared by the Tennessee Valley Authority.
[4] Experimental granular high-alumina nitric phosphate prepared by the Tennessee Valley Authority.
[5] Commercial granular nitric phosphate.
[6] Commercial prilled ammonium nitrate.

Equipment and Procedures

The drillability tests were conducted in the air-controlled room at the Agricultural Engineering Research Division Laboratory at Beltsville, Md. The room, which measures 16 by 24 feet with a 9½-foot ceiling, has 2 inches of cork insulation under the concrete floor. The walls and ceiling are insulated with cork 4 inches thick. Temperature and humidity were controlled during the tests at 75° F. (±1°) and 88 percent (±2 percent), respectively.

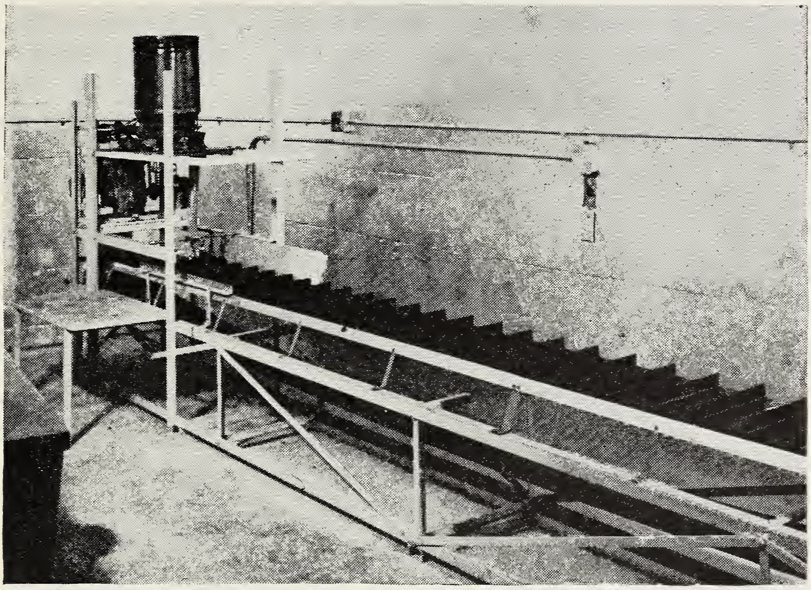
The air-controlling equipment in the room consists of an electric heating unit, a 5-horsepower refrigeration unit, and an electrically heated water vaporizer. Air circulation during the tests was maintained through 2 cage-type blowers in the air conditioner and several 15-inch-blade circulating fans.

The testing apparatus was built by the staff of the Planting and Fertilizing Equipment and Practices Section, Crop Production Engineering Research Branch, Agricultural Engineering Research Division, ARS. The uniformity testing machine consists of: A frame 20 feet long; an adjustable support for mounting different types of fertilizer hoppers; an endless belt 12 inches wide, mounted in a horizontal position, with 17 feet of the belt having dividers spaced 6 inches apart upon which fertilizer from the hoppers may be deposited; and a 1-horsepower electric motor. The belt and hopper are connected to the power unit through individual power trains with jaw clutches, so that both belt and hopper can be run individually or simultaneously and at various speeds. A photograph and a diagram of the machine are given (figs. 1 and 2, respectively).

Material dropped on the spaces between the dividers is collected after the belt is stopped. The amounts are then weighed individually to determine uniformity of application.

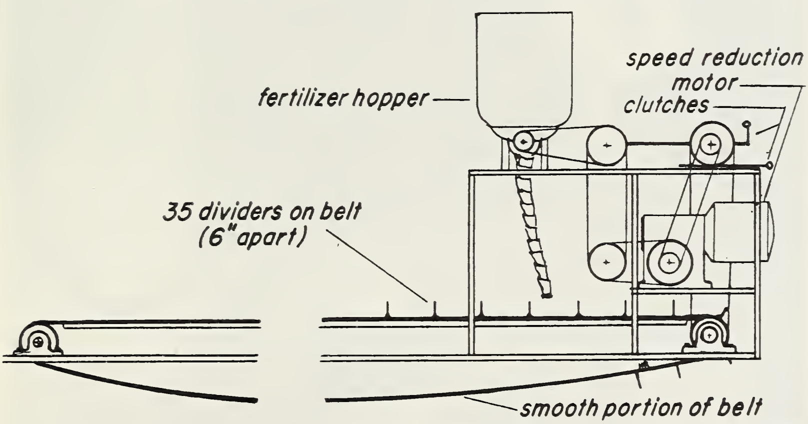
A rotating-plate type of fertilizer hopper is used to a great extent on farm machines. This was used in the tests because preliminary tests had shown that the rotating-plate drill has the following distinct advantages: It distributes granular fertilizer more uniformly than does the star-wheel drill, during the short period of time required for each drilling test; and its less positive action is accompanied by a greater decrease in drilling rate with increase in moisture content of the exposed fertilizers. Thus, the effects of small moisture changes become more noticeable when the rotating-plate drill is used.

The drill speed for these tests was set to conform to the manufacturer's recommendation for a vehicle speed of 3 miles per hour (m. p. h.). The belt was driven at a uniform speed of about 1.5 m. p. h. As the belt moved at this speed, its 6-inch sections collected an amount of fertilizer equal to that distributed along 1 foot of ground by a drill traveling at the rate of 3 m. p. h.



BN-5378

FIGURE 1.—Machine for testing drillability of fertilizers.



BN-5379

FIGURE 2.—Diagram of machine for testing drillability of fertilizers (side view).

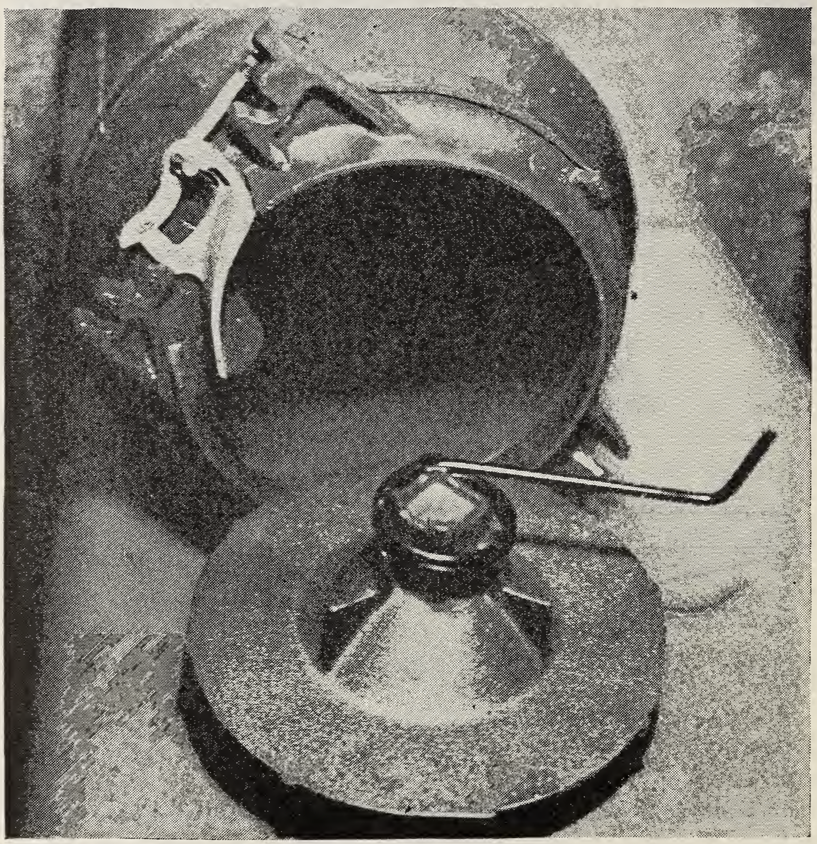
The rotating-plate hopper is shown (fig. 3). Fertilizer is discharged from the hopper, through an adjustable gate and a flexible tube, either onto the belt or into the weighing pans, as desired. In these tests, the initial drilling rates of the different mixtures varied between 300 and 500 pounds per acre, calculated on a row spacing of 40 inches.

Twenty-seven pounds of the fertilizer to be tested was placed in the hopper and drilled 8 minutes to attain normal flow. Material dis-

charged was returned to the hopper at intervals. With all the fertilizer in the hopper, the mixture was then drilled onto the moving belt, with the outlet to the delivery tube clamped in a vertical position above the center of the belt. The material on 25 consecutive 6-inch sections was removed to individual containers and weighed.

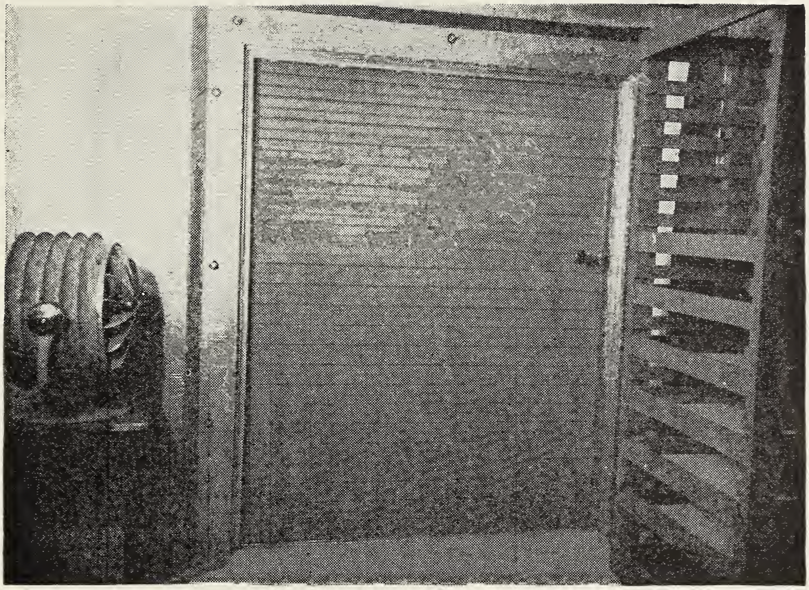
The remainder of the material was then placed in trays 16 by 28.5 by 2.5 inches in size and leveled to a depth of 5/16 inch. The trays were placed 5 inches apart in a rack to provide equivalent exposure of the material in all the trays. A 15-inch fan, located some 6 feet from the rack, circulated air over the trays (fig. 4).

After 30 minutes of exposure, the fertilizer was stirred by hand to aid in uniform moisture absorption throughout the mass. After an hour's exposure, it was taken off the trays and mixed, and a sample was taken for determination of moisture. The procedure of exposing,



BN-5380

Figure 3.—Rotating-plate fertilizer hopper with gate adjustment. The rotating plate is shown in the foreground.



BN-538

FIGURE 4.—Fan and exposure trays in constant-humidity room.

stirring, and drilling the fertilizer was repeated until the material failed to drill or until the total exposure period was 5 hours. A material was deemed undrillable when it caked in the drill or when the observed flow was erratic.

The drilling rate was indicated by the total weight of material (dry basis) collected on 25 sections of the belt. The *relative* drilling rate was determined by dividing the test drilling rate by the original drilling rate; this was expressed in terms of percentage. An analysis of variance was made of the drilling rates to determine the level (5 percent or 1 percent) at which the rates were significantly different.

Coefficient of Variation

The coefficient of variation (*5*, *8*) of the drilling rate is a measure of the uniformity with which a material is drilled. It was calculated from the weights of fertilizer collected on 25 consecutive sections of the belt. The coefficient of variation, in percent, is expressed by the formula,

$$\frac{\sqrt{\frac{\sum(X-M)^2}{n-1}}}{M}\times 100,$$

where X=any one variate (weight)
n=total number of variates
M=mean
$\sum$=sum of

TABLE 2.—*Effect of exposure on relative drilling rates, coefficients of variation, and moisture content of different fertilizers*

Sample number	Nominal grade	Initial moisture,[1] dry basis	Relative drilling rate and coefficient of variation												Length of time material remained drillable	Range of moisture content, dry basis, within which material became undrillable
			Hours of exposure													
			0		1		2		3		4		5			
			Rate	Coefficient	Rate	Coefficient	Rate	Coefficient	Rate	Coefficient	Rate	Coefficient	Rate	Coefficient		
		Percent	*Percent*		*Percent*		*Percent*		*Percent*		*Percent*		*Percent*		*Hours*	*Percent*
1	5–20–20	3.8	100	7.7	99	6.6	99	5.2	(2)	------	------	------	------	------	2	8.8–11.5
2	6–8–4	2.9	100	7.4	97	8.3	52**	12.4	(2)	------	------	------	------	------	2	7.0–8.8
3	6–9–12	1.7	100	10.4	88**	6.2	53**	14.4	(2)	------	------	------	------	------	2	6.7–8.4
4	8–12–12	1.0	100	8.2	90**	5.7	60**	9.0	(2)	------	------	------	------	------	2	5.1–7.5
5	8–16–16	1.9	100	10.3	101	10.0	81**	11.1	(2)	------	------	------	------	------	2	7.3–9.9
6	8–24–0	3.7	100	7.1	97	6.5	91**	6.9	81**	4.8	65**	6.0	(2)	------	4	12.2–13.8
7	11–11–11	1.3	100	11.3	92**	10.7	65**	12.1	(2)	------	------	------	------	------	2	7.1–9.9
8	11–22–11	2.0	100	9.7	99	8.3	98	10.7	99	11.0	102	10.8	101	8.4	>5	[3] 16.2
9	12–12–12	1.5	100	6.4	88**	7.9	(2)	------	------	------	------	------	------	------	1	4.8–7.9
10	12–12–12	1.3	100	10.9	89**	7.7	(2)	------	------	------	------	------	------	------	1	4.4–7.7
11	14–11–11	3.2	100	13.7	(2)	------	------	------	------	------	------	------	------	------	<1	3.2–8.0
12	15–10–10	.6	100	13.2	99	10.7	(2)	------	------	------	------	------	------	------	1	3.4–6.3
13	17–22–0	.8	100	12.9	57**	15.2	(2)	------	------	------	------	------	------	------	1	4.6–8.5
14	33–0–0	.2	100	9.0	(4)	------	------	------	------	------	------	------	------	------	⅓	1.5

[1] Moistures determined by vacuum-desiccation method approved by the Association of Official Agricultural Chemists (*1*).
[2] Failed to drill.
[3] Moisture content after 5 hours of exposure.
[4] Failed; became undrillable after 20 minutes of exposure on trays.
**Significantly different at 1-percent level.

Test Results

The relative drilling rates, coefficients of variation, and moisture contents of the different fertilizers at various stages of exposure are given (table 2).

Of the materials tested, 2 became undrillable before 1 hour of exposure, 4 before 2 hours, 6 before 3 hours, and 1 before 5 hours. The 11–22–11 high-alumina nitric phosphate remained drillable after 5 hours of exposure, but the prilled ammonium nitrate was undrillable after only 20 minutes. Between these extremes were the high-nitrogen mixtures (12 percent N or more), which became undrillable in less than 2 hours of exposure, and the other mixtures, which were undrillable after 2 hours.

Drilling tests at intervals of 1 hour do not allow close comparison of different samples with respect to the exact time and moisture content at which they become undrillable. However, a comparison of their drilling rates for the last hour before failure indicates the relative drillability and final moisture content of different materials which failed to drill within the same hour.

The prilled ammonium nitrate was undrillable at 1.5-percent moisture content; the high-nitrogen mixed fertilizers became undrillable in the moisture-content range of 3.2 to 8.0 percent; the 8–24–0 became undrillable in the range of 12.2 to 13.8 percent; and the 11–22–11 remained drillable at 16.2 percent.

In previous work (*10*) it was found that materials of low initial moisture content remained drillable for longer periods of time, but became undrillable at about the same moisture content as did materials of high initial moisture content.

When the material was drilled on the belt, the coefficients of variation of the drilling rates ranged from 4.8 to 15.2 percent for the fertilizers in drillable condition (see table 2).

SUMMARY and CONCLUSIONS

The method of determining the relative drillability of fertilizers with the facilities developed for this type of test gave satisfactory results in the study reported in this publication. It is felt that this special laboratory testing apparatus will meet most of the requirements for determining the drillability characteristics of present fertilizers with respect to moisture absorption during the drilling operation.

The results of the drillability tests, supplemented by previously published results obtained with the same equipment (*9*, *10*), indicate that the drilling characteristics of most fertilizers lie somewhere between those of prilled ammonium nitrate and the 11–22–11 high-alumina nitric phosphate. In these tests, the drilling properties of the

prilled ammonium nitrate samples were found to be relatively poor. However, this type of nitrogen fertilizer has been used on farms for a number of years.

Any fertilizer possessing drilling properties superior to those of prilled ammonium nitrate may be considered drillable under normal conditions of application in the field. All the materials described in this publication were found to be superior to prilled ammonium nitrate in drillability, and most of them were far superior. Any material that approaches the 11–22–11 high-alumina nitric phosphate in drilling properties may be considered excellent.

LITERATURE CITED

(1) Association of Official Agricultural Chemists.
1955. vacuum-desiccation method—official. Ed. 8, p. 7.

(2) Deming, W. E., and Mehring, A. L.
1929. the gravitational flow of fertilizers and other comminuted solids. Indus. and Engin. Chem. 21: 661–665, illus.

(3) Mehring, A. L.
1929. factors affecting the drillability of fertilizers. Indus. and Engin. Chem. 21: 1219–1223, illus.

(4) ———
1931. measurement of drillability of fertilizers. Indus. and Engin. Chem., Analyt. Ed. 3: 34–38, illus.

(5) ——— and Cumings, G. A.
1932. effects on cotton of irregular distribution of fertilizers. Jour. Agr. Res. 44: 559–570, illus.

(6) ——— and Cumings, G. A.
1930. factors affecting the mechanical application of fertilizers to the soil. U. S. Dept. Agr. Tech. Bul. 182, 96 pp., illus.

(7) ——— White, L. M., Ross, M. H., and Adams, J. E.
1935. effects of particle size on the properties and efficiency of fertilizers. U. S. Dept. Agr. Tech. Bul. 485, 27 pp., illus.

(8) Paterson, D. D.
1939. statistical technique in agricultural research. Ed. 1, 263 pp., illus. New York.

(9) Rapp, H. F., and Hardesty, J. O.
1955. storage and drilling characteristics of high-alumina nitric phosphate prepared from florida leached-zone ore. Jour. Agr. and Food Chem. 3: 1026–1028.

(10) ——— and Hardesty, J. O.
1957. granulation of mixed fertilizers in experimental equipment and determination of storage and drilling characteristics of the products. Jour. Agr. and Food Chem. 5: 426–433, illus.

(11) Ross, W. H., Adams, J. R., Yee, J. Y., and others.
1946. preparation of ammonium nitrate for use as a fertilizer. U. S. Dept. Agr. Tech. Bul. 912, 80 pp., illus.

U. S. GOVERNMENT PRINTING OFFICE: 1958